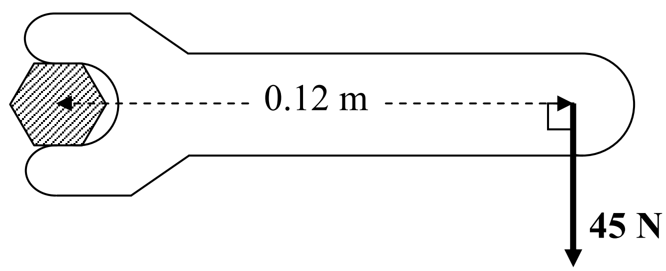
The Concept of Torque

Think back to the introduction of the last section of notes. There, you learned that if an object has two or more forces acting on it *and* these forces do not act at exactly the same point, then the object will spin, or rotate. The twisting effect of a force is called *torque*.

Torque τ = (applied perpendicular force) x (distance to pivot)

$\tau = \mathbf{F \times d}$ (measured in Newton-meters, or N-m)

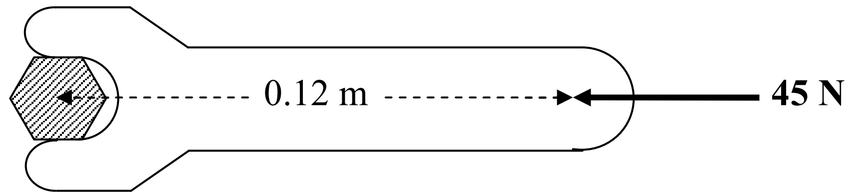
Consider the diagram below. A wrench is used to turn a nut clockwise. For the nut to turn, a force of 45 N acts perpendicular to a distance of 0.12 m from the center of the bolt – i.e., the *pivot* point about which the wrench will turn.



The torque here is calculated to be **τ = 45(0.12) = 5.4 N-m**, in a *clockwise* direction. Note the following:

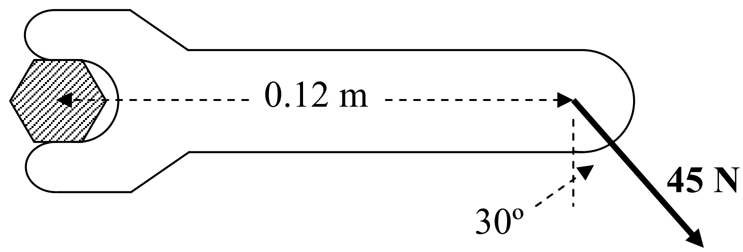
- to calculate torque, you must be able to identify where the system will rotate (the pivot), as well as how far away from the pivot the perpendicular force acts.
- torque can be increased or decreased by changing the force that acts on the wrench.
- torque can also be increased or decreased by changing the distance that the force acts away from the pivot; this is why a longer wrench can turn a "tough" nut more easily than a short wrench – the longer wrench produces a greater torque.
- since torque causes rotation, it must be described in terms of *clockwise* (cw) or *counterclockwise* (ccw) motion.

Once more important point: a torque can only occur if the acting force is perpendicular to the distance from a pivot. This should not surprise you; after all, what would happen if the force on the wrench above was acting parallel to the distance from the pivot?

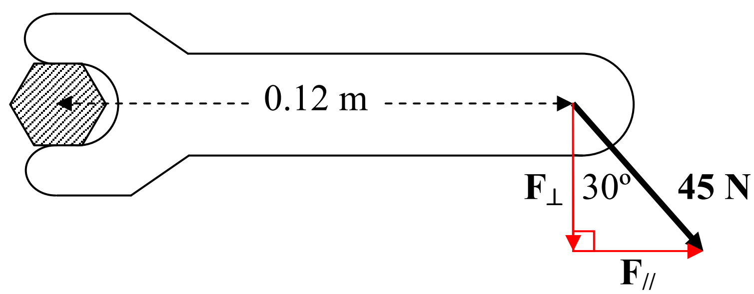


Clearly, the wrench won't turn in this case (though it might break if the force is large enough). In other words, no torque will happen in this arrangement.

What happens if the same force acts at some angle to the distance from the pivot, as shown below?



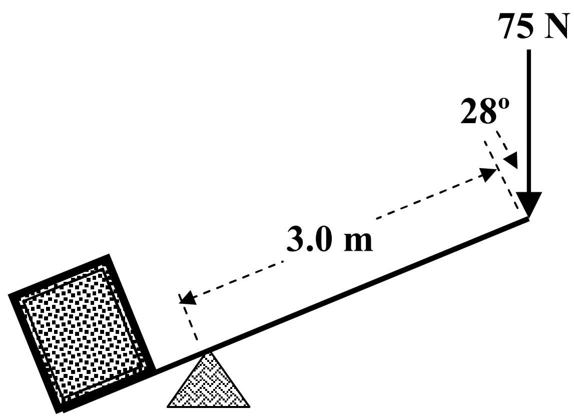
The wrench will turn, but with a reduced torque. To determine the magnitude of this torque, components of the force vector must be taken that are parallel ad perpendicular to the distance from the pivot:



- The parallel component $\mathbf{F}_{//}$ produces no torque and can be ignored.
- The perpendicular component $\mathbf{F}_{\perp}$, which provides the torque to turn the wrench, can be calculated:

$\mathbf{F}_{\perp} = \mathbf{45 \cos 30 = 39\ N}$ → torque $\boldsymbol{\tau} = \mathbf{39(0.12) = 4.7\ N\text{-}m}$

Example #7. A smart physics student attempts to lift a heavy crate by using a lever system. She pushes on the lever with a force as shown below. What torque is created by this student?

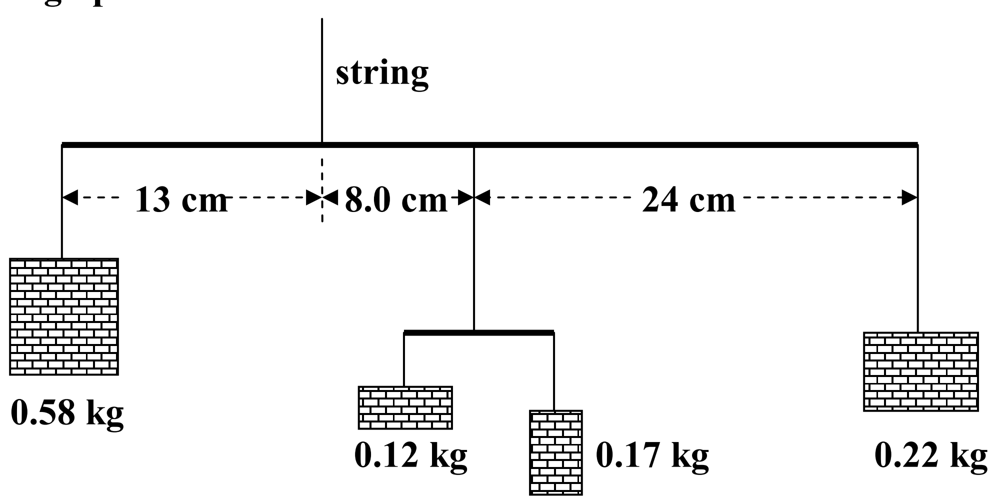


(see Equilibrium Ex 7 for answer)

One last point: *clockwise* rotations around a pivot oppose *counterclockwise* rotations around the same pivot. To determine the net torque on a system, you need to compare the total clockwise torques to total counterclockwise torques. If one is greater, the system will start to rotate.

To summarize: in tackling torque problems, it is always best to:
a) identify the pivot (more on this later);
b) calculate each torque (using trig if necessary to find perpendicular force components);
c) classify each torque as 'cw' or 'ccw' and add or subtract accordingly to find the net torque.

Example #8. A group of physics students attempt to balance a mobile unsuccessfully. Examine the diagram below and calculate the net torque on the large beam that will cause the mobile to start tilting in one direction once it is hung up.



(see Equilibrium Ex 8 for answer)